AN INTRODUCTION TO THE COSMOS SURVEY

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ABSTRACT

We describe the principal characteristics of the COSMOS imaging data, an extensive multi-wavelength survey which provides an unparallelled view of the Universe at \(z \sim 1\).

Key words: cosmology: observations — cosmology: large scale structure of universe — cosmology: dark matter — galaxies: formation — galaxies: evolution — surveys.

1. INTRODUCTION

Considerable progress has been made in the last decade towards mapping the evolution of galaxy populations across cosmic times. Nevertheless, our picture is still incomplete. Certain regions of parameter space are well covered but wide gaps remain in others. In particular, the role played by environment at high redshift is for the moment largely unexplored. Addressing this question was one of the main goals of the COSMOS project which comprises an equatorial 2 deg\(^2\) field which has been observed by almost every large astronomical facility, starting with 575 orbits of the ACS camera on the Hubble space telescope (Scoville et al., 2007). In Figure 1 we show a slice of the Universe at \(z \sim 1\) with the angular field-of-view corresponding to the COSMOS survey. The underlying grey-scale shows the distribution of dark matter in a large cosmological simulation. Overlaid on this plot are circles representing galaxies generated by a semi-analytic galaxy formation model.

This Figure demonstrates that galaxy properties depend strongly on their local environment. In the model, galaxies with red rest-frame colours (darker circles) form preferentially in high-density environments, whereas the bluer objects are distributed uniformly across the field of view. Inset are the fields of view of some other recent surveys such as the “GOODS” project (Dickinson et al., 2003) or the Hubble deep field survey (Williams et al., 1996). The small angular extent of these surveys means that they are sensitive to the effects of “cosmic variance” and as such do not probe a representative range of local densities.

2. COSMOS PHOTOMETRIC DATA

In Figure 3 we show the current wavelength coverage and magnitudes limits as of March, 2009 for the COS-
Figure 2. Comparison of COSMOS point spread function at different wavelengths from GALEX (ultraviolet) to Spitzer (mid infrared).

Figure 3. Current limiting magnitudes of the COSMOS survey (5σ, 3″ aperture; March 2009, Courtesy P. Capak)

MOS optical and near-infrared wavebands. These limiting magnitudes are defined based on n 5σ noise measurements in 3″ apertures. This extensive wavelength coverage to these depths over such a large field of view is unique amongst current surveys. Figure 2 illustrates the typical image quality and surface brightness limits for COSMOS data from UV (GALEX) to mid-IR (Spitzer IRAC).

COSMOS photometric data also includes extensive coverage at longer wavebands, including near-infrared images from the WIRCAM camera at CFHT (McCracken et al, submitted) and the sCOSMOS survey (Sanders et al., 2007).

3. COSMOS PHOTOMETRIC REDSHIFTS

Large surveys such as zCOSMOS (Lilly et al., 2007) will provide precise spectroscopic redshifts for around 20,000 bright galaxies to $i < 22.5$ and around 10,000 fainter galaxies selected in multi-colour space to lie approximately at $z \sim 2$. Unfortunately, this is only a tiny fraction of the total numbers of objects in the COSMOS field, and many astrophysical problems could greatly benefit from even approximate distance information. Using the zCOSMOS redshifts to provide calibration information, Ilbert et al. (2009) computed “photometric redshifts” for a large sample of galaxies to $i < 26.5$. In this technique, model galaxy spectral energy distributions at a grid of redshifts are compared to observed photometric measurements.

Ilbert et al.’s photometric redshifts were computed using the 30-band COSMOS photometric data and represent the most accurate photometric redshifts for the largest sample of galaxies at these depths to date. Figure 4 from Ilbert et al. shows these photometric redshifts compared to spectroscopic ones for the zCOSMOS-bright sample. The number of catastrophic outliers ($\eta$) is under 1% and the overall photometric redshift accuracy better than 1%.

The extensive coverage of the COSMOS field in near-infrared bands means that photometric redshifts can be computed relatively even in the redshift range $1 < z < 2$. At redshifts greater than $\sim 1.5$ the Balmer break feature moves out of the optical window, and without adequate near-infrared data, photometric redshift codes confuse Balmer and Lyman-break features. This can result in a large number of catastrophic outliers in the redshift range $1 < z < 2.5$. From Figure 5 it is evident that in the COSMOS data, the presence of the additional near-infrared data ensures that the number of catastrophic outliers (parametrised by $\eta$) is low.

4. LARGE SCALE STRUCTURES IN THE COSMOS SURVEY

The COSMOS field provides an unparallelled view of the Universe at intermediate redshifts. Figure 6 shows the angular correlation $w$ computed in McCracken et al. (2007) for all galaxies selected as a function of apparent magnitude. The solid line shows the predictions from the semi-analytic model of Kitzbichler & White (2007). At most magnitude bins, the agreement between simulations and observations is remarkably good.

One of the principal aims of the COSMOS project is to investigate the relationship between dark matter and galax-
Figure 5. Photometric redshifts for faint, infrared-selected galaxies from Ilbert et al. (2009)

ies at $z \sim 1$. In Figure 7 we show the projected dark matter mass map for the COSMOS field (contours) compared to the underlying stellar mass (blue/grey scale). In their paper, Massey et al. also computed the projected mass map over three different redshift intervals, something which was only possible for the COSMOS field thanks to the unique combination of precise photometric redshifts and accurate shape measurements provided by the HST ACS imaging.

5. COSMOS IN THE CONTEXT OF THE VIRTUAL OBSERVATORY PROJECT

The COSMOS project could potentially benefit from tools under development for the Virtual Observatory project. COSMOS is qualitatively different from other surveys such as the SDSS in that although the solid angle sky coverage is much smaller the information content per object is much higher. In optical and near-infrared wavelengths, cross-identification between different bands is theory trivial, but in practice the choice of detection and measurement wavelengths can impact adversely scientific exploitation of the resulting catalogues. It is usually the case that one tries to generate a “one size fits all” catalogue to address as wide a possible range of scientific problems. In an ideal world, on-the-fly catalogue generation tuned to a specific astrophysical problem combined with an automatic cross-matching to existing known sources could greatly increase the scientific value of the underlying imaging data.

At longer wavelengths dealing with confusion and source deblending becomes increasingly challenging. In recent years “stacking” analyses, in which “postage-stamp” images extracted at a given shorter-wavelength position for a given class of objects are coadded to provide upper limits or flux detections for that object class at longer wavelengths. This very powerful technique has pushed flux sensitivities several orders of magnitude fainter in comparison to single object studies. An automatic stacking facility would be a powerful addition to the astronomer’s toolkit; stocking (and maintaining the most recent versions) the pixel data locally is often not an option.

In dealing with datasets like COSMOS it becomes rapidly apparent that complete knowledge of all data products at each wavelength is beyond the capabilities of a single astronomer. However, such knowledge is exactly what is required if effective cross-wavelengths studies are to be carried out. It therefore seems more important than ever to design a (searchable) way to describe each data set and which encapsulates all the relevant information currently locked in journal articles describing each science product, including spatial depth variations, point spread functions and masking information.

6. PLANNED EXTENSIONS TO THE SURVEY

Over the next five years, starting in 2010, the VISTA telescope will carry out an ultra-deep survey, UltraVISTA, of the COSMOS field in near-infrared wavebands. The Ultra-VISTA survey expected to reach $5\sigma$ point-source depths of 26.7, 26.6, 26.1, 25.6, in Y, J, H and $K_s$ respectively. This survey is expected to find around 1000 galaxies with $z > 6.5$ and will be pathfinder mission for future space-based observatories like JWST. Coverage of the COSMOS field is also planned for the Herschel satellite guaranteed time observations. In the longer term, most large planned future facilities such as ALMA (Atacama large millimetre array) will include observations of the COSMOS field. It seems that the flood of astrophys-
Figure 7. Reconstructed dark matter density (contours) compared to underlying stellar mass (blue/grayscale) for the COSMOS field (adapted from Massey et al., 2007)

...ical data covering the COSMOS field will not cease for the foreseeable future.

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REFERENCES